Copy ______

IDA PAPER P-3083

EXTERNAL INDEPENDENT READINESS REVIEW: EOS AM-1 CDR

David Braverman
Charles W. Cook
William A. Jeffrey
Robert E. Roberts
Maile E. Smith
Institute for Defense Analyses

Thomas R. Buckler
Buckler Communications

Nelson Hyman
Paul Regeon
Jeffrey Short
Charles Wilderman
Naval Research Laboratories

Ernest Scheyhing
Aerospace Corporation

July 1995

Prepared for
National Aeronautics and Space Administration

INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

IDA Log No. H 95-46764

DEFINITIONS

IDA publishes the following documents to report the results of its work.

Reports

Reports are the most authoritative and most carefully considered products IDA publishes. They normally embody results of major projects which (a) have a direct bearing on decisions affecting major programs, (b) address issues of significant concern to the Executive Branch, the Congress and/or the public, or (c) address issues that have significant economic implications. IDA Reports are reviewed by outside panels of experts to ensure their high quality and relevance to the problems studied, and they are released by the President of IDA.

Group Reports

Group Reports record the findings and results of IDA established working groups and panels composed of senior individuals addressing major issues which otherwise would be the subject of an IDA Report. IDA Group Reports are reviewed by the senior individuals responsible for the project and others as selected by IDA to ensure their high quality and relevance to the problems studied, and are released by the President of IDA.

Papers

Papers, also authoritative and carefully considered products of IDA, address studies that are narrower in scope than those covered in Reports. IDA Papers are reviewed to ensure that they meet the high standards expected of refereed papers in professional journals or formal Agency reports.

Documents

IDA Documents are used for the convenience of the sponsors or the analysts (a) to record substantive work done in quick reaction studies, (b) to record the proceedings of conferences and meetings, (c) to make available preliminary and tentative results of analyses, (d) to record data developed in the course of an investigation, or (e) to forward information that is essentially unanalyzed and unevaluated. The review of IDA Documents is suited to their content and intended use.

The work reported in this document was conducted under contract DASW01 94 C 0054 for the Department of Defense. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

IDA PAPER P-3083

EXTERNAL INDEPENDENT READINESS REVIEW: EOS AM-1 CDR

David Braverman
Charles W. Cook
William A. Jeffrey
Robert E. Roberts
Maile E. Smith
Institute for Defense Analyses

Thomas R. Buckler
Buckler Communications

Nelson Hyman
Paul Regeon
Jeffrey Short
Charles Wilderman
Naval Research Laboratories

Ernest Scheyhing
Aerospace Corporation

July 1995

IDA

INSTITUTE FOR DEFENSE ANALYSES

Contract DASW01 94 C 0054
Task T-AG1-1369

PREFACE

IDA was tasked by NASA Headquarters, Code YF, to conduct an External Independent Readiness Review (EIRR) of the EOS AM-1 spacecraft following the Critical Design Review (CDR) milestone. The EIRR is not intended to supplant the normal Goddard Space Flight Center (GSFC) review process nor to require additional design reviews. The total EIRR process will comprise three separate reviews conducted at these program milestones: CDR (February 1995), Pre-Environmental Review (February 1997), and Pre-Ship Review (February 1998). The reviews will be independently reported to the Associate Administrator, Mission to Planet Earth (MPTE). The NASA coordinator for this first review is Mr. Ronald R. Felice, Program Manager, EOS-AM Missions, MPTE Flight Systems Division, NASA Headquarters.

CONTENTS

I. INTRODUCTION

I. INTRODUCTION

The Earth Observation System (EOS) Program will develop and launch a space-based observation system that will provide global Earth coverage on a long-term sustained basis. The objective is to collect data to allow the multidisciplinary study of the Earth's interrelated processes (atmosphere, oceans, and land surface) and their relationship to environmental changes. To achieve these objectives, NASA will launch a series of spacecraft to maintain a continuous 15-year data record. These spacecraft will be put into sun-synchronous orbits with a morning descending equatorial crossing (designated AM satellites) and afternoon ascending equatorial crossing (designated PM satellites). The global change research emphasized with the AM instrument data sets includes cloud physics and atmospheric radiation properties in addition to terrestrial and oceanic surface characteristics. The EOS AM-1 spacecraft, the subject of this review, will have a payload complement consisting of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER); the Cloud and Earth's Radiant Energy System (CERES); the Multi-angle Imaging Spectro-Radiometer (MISR); the Moderate Resolution Imaging Spectro-Radiometer (MODIS); and Measurements of Pollution in the Troposphere (MOPITT). The spacecraft will have a minimum design lifetime of 5 years, and will be inserted into a 16-day orbit repeat with a 10:30 AM descending nodal crossing time (nominally 705 km, 98.2° inclination). The spacecraft will support the intermittent direct down link of the ASTER science data, the X-band continuous direct-to-ground broadcast of MODIS science and ancillary data, and the intermittent direct-to-ground down link of stored science and engineering data as well as having the capability to transmit its data through the Tracking and Data Relay Satellite System (TDRSS). The spacecraft is scheduled for a June 1998 launch on an Atlas IIAS vehicle from Vandenberg Air Force Base.

OUTLINE

This chart indicates the outline to be followed for the briefing. The Overview discussion will cover the EIRR participants, the EIRR process, and the Overall Assessment resulting from the EIRR. The Spacecraft Systems Assessment will contain a subsystem-by-subsystem assessment for the EOS AM-1 spacecraft. This will be followed by a discussion of higher level concerns, namely, Program-Level Concerns. The briefing will end with a Summary and Recommendations.

IDA

OUTLINE

- Overview
  - Participants
  - Process
  - Overall Assessment
- Spacecraft Systems Assessment
- Program-Level Concerns
- Summary and Recommendations

II. OVERVIEW

PARTICIPANTS

The EIRR Panel comprised a team of 11 people headed by the Institute for Defense Analyses (IDA) and chaired by Dr. Robert E. Roberts, IDA Vice President-Research. Panel members from the Institute for Defense Analyses included Dr. David Braverman, Dr. Charles W. Cook, Dr. William A. Jeffrey, and Dr. Maile E. Smith. In addition, the following members were designated by the Program Manager, EOS-AM Missions, NASA Headquarters: Dr. Ernest R. Scheyhing, The Aerospace Corporation; Mr. Thomas R. Buckler, Buckler Communications; and Dr. Nelson Hyman, Dr. Paul Regeon, Dr. Jeffrey Shortt, and Dr. Charles Wilderman, Naval Research Laboratory.

IDA

PARTICIPANTS

- Institute for Defense Analyses:
  - Robert Roberts - Chairman
  - David Braverman
  - Charles Cook
  - William Jeffrey
  - Maile Smith
- Aerospace Corporation:
  - Ernest Scheyhing
- Buckler Communications:
  - Thomas Buckler
- Naval Research Laboratory:
  - Nelson Hyman
  - Paul Regeon
  - Jeffrey Shortt
  - Charles Wilderman

PROCESS

The specific objectives of the EIRR at the CDR Milestone were threefold: To conduct an independent review of the basic spacecraft design and payload interfaces, to identify risk areas which may affect mission success, and to serve as a tutorial for the EIRR Panel for future reviews that they will be conducting.

In the course of conducting the CDR EIRR, the Panel attended and participated in the following EOS AM-1 meetings and reviews:

- EIRR Definition and Tasking with Ronald R. Felice, Program Manager, EOS-AM Missions at NASA Headquarters, on January 11, 1995.
- Critical Design Review Pre-Brief conducted by the EOS AM Project Office, Goddard Space Flight Center (GSFC), on January 18, 1995.
- Critical Design Review (CDR) conducted by Martin Marietta Astro Space (MMAS), Valley Forge, Pennsylvania, from January 31 through February 2, 1995.
- CDR Follow-Up Discussions with EOS AM Project Office, GSFC, on February 13, 1995.
- EOS AM-1 Software CDR held at MMAS, Valley Forge, Pennsylvania, on February 15, 1995.
- EIRR Briefing by the EOS AM-1 Panel to the Program Manager, EOS-AM Missions, NASA Headquarters, on February 28, 1995.
- EIRR: EOS AM-1 CDR Final Briefing to Associate Administrator & Staff, Mission to Planet Earth, NASA Headquarters, on March 8, 1995.

In addition to the above meetings, representatives of the Panel attended an informal critique of the EOS AM-1 CDR conducted by Code 300, NASA Goddard, on February 6, 1995.

IDA

PROCESS

Objectives:

- EIRR of Basic S/C Design and P/L Interfaces
- Identify Risk Areas Which May Affect Mission Success
- Serve as a Tutorial for the EIRR Panel for Future Reviews

Meetings:

1/11	EIRR Defined w/Ron Felice	NASA HQ
1/18	Project Office CDR Pre-Brief	GSFC
1/31-2/2	Critical Design Review	MMAS
2/13	Follow-Up With Project Office	GSFC
2/15	Software CDR	MMAS
2/28	EIRR Brief to Project Office	NASA HQ
3/8	EOS AM-1 CDR Final	NASA HQ

OVERALL ASSESSMENT

The overall assessment by the External Independent Review Panel indicated that the CDR demonstrated that the EOS AM-1 spacecraft has a mature design that is accompanied by a detailed test plan to prepare it for its scheduled launch in 1998.

The CDR also showed that there are no apparent critical problems (no "show stoppers") that will prevent the spacecraft from achieving a successful mission. It is evident from the CDR and other review activities that NASA Goddard is working closely with Martin Marietta Astro Space to accomplish a satisfactory program and a successful EOS AM-1 mission.

However, there were a number of items of concern to the Review Panel regarding the EOS AM-1 spacecraft. These concerns are the following:

1. Little or no space heritage on many components—there are numerous instances of hardware incorporated into the EOS AM-1 spacecraft design that involve new or extensively modified designs over what has been previously flown and demonstrated in space flight.
2. Technical capabilities have yet to be fully demonstrated—to date, there are numerous instances where components and subsystems have not completed technical testing and verification.
3. The design of the spacecraft and its specifications are heavily driven by two of the instruments: MOPITT and especially ASTER. The incorporation of the necessary features to accommodate these instruments, such as power, data rate, cooling, and appropriate launch vehicle results in increased cost and schedule risk.
4. The inclusion in the program of the use of new facilities, including the Atlas IIAS launch site, launch processing, and the MMAS Integration and Test (I&T) building, contributes to increased schedule risk.

IDA

OVERALL ASSESSMENT

- Critical Design Review Indicated Mature Design and Detailed Test Plan
- No “Show Stoppers” Evident
- NASA is Working Closely With MMAS to Ensure a Successful Program
- Concerns:
  - New and Modified Hardware Increases Schedule Risk
  - Numerous Technical Capabilities Have Yet to be Fully Demonstrated
  - Design of Spacecraft Driven by ASTER and MOPITT
  - New Facilities Provide Schedule Risk

OUTLINE

As shown in Chart 5, an assessment of each of the major subsystems of the EOS AM-1 spacecraft will now be discussed. The major subsystems comprise Structures and Mechanisms; Thermal Control; Electrical Power; Guidance, Navigation and Control; Propulsion; Command and Data Handling and Software; Communications; and Integration and Testing and Operations.

IDA

OUTLINE

- Overview
- Spacecraft Systems Assessment
  - Structures and Mechanisms
  - Thermal Control
  - Electrical Power
  - Guidance, Navigation, and Control
  - Propulsion
  - Command and Data Handling and Software
  - Communications
  - Integration and Testing and Operations
- Program-Level Concerns
- Summary and Recommendations

III. SPACECRAFT SYSTEMS ASSESSMENT

STRUCTURES AND MECHANISMS

The spacecraft subsystem for Structures and Mechanisms contains a number of elements, including the primary structure, equipment and propulsion modules, kinematic mounts, mechanism for the deployment of the high gain antenna, solar array drive, and structural adaptations for instrument accommodation.

In contrast to the normally used components, aspects of the structures and mechanisms subsystems that incorporate new hardware or new capabilities include the use of high modulus graphite-epoxy (GrEp) truss tubes for structural members and non-explosive actuators (NEAs) for the release of mechanisms involved in on-orbit deployment sequences of other subsystems.

The assessment of the review panel with regard to the status of the structures and mechanisms subsystem is that the engineering design is nearly complete, the major issues are identified, and no major concerns are evident.

It does appear, however, that plans for transporting the spacecraft to the Vandenberg AFB launch site by C5A transport are still in the early stages. To avoid a possible structural redesign of the spacecraft, it is necessary that much greater attention be paid to the detailed planning of the C5A interface.

IDA

STRUCTURES AND MECHANISMS

- **Components:**
  - Primary Structure, Equipment and Propulsion Modules, Kinematic Mounts, High Gain Antenna Deployment Mechanism, Solar Array Drive, Instrument Accommodation
- **New Hardware and New Capabilities:**
  - High Modulus Graphite-Epoxy Truss Tubes
  - Non-Explosive Actuators (NEAs)
- **Assessment:**
  - Engineering Design Nearly Complete and Major Issues Identified
  - S/C Transportation Planning Requires Greater Detail (Plans for C5A Transport Appear to be in Preliminary Stage)

STRUCTURES AND MECHANISMS (CONTINUED)

Because of the high levels of shock associated with the conventional pyrotechnic explosive actuators, NEAs have recently [since preliminary design review (PDR)] been incorporated into the spacecraft design. These are *new* designs that do not have space operation heritage. The use of actuators for deployments of critically important components relating to the operation of the spacecraft means that successful operation of the NEAs is vital to mission success. It is therefore very important that the planned tests and procedures relating to the use of these actuators be closely monitored and checked to achieve the greatest probability of successful operation on-orbit.

The solar array deployment (SAD) mechanism has been identified as an area that clearly has potential single point failure aspects. Complete and proper solar array deployment is critical to the successful operation of the spacecraft. Without the benefit of redundancy or fault tolerance, the SAD must operate as planned. To help assure such operation, close supervision of tests and manufacturing procedures must be maintained.

Being a relatively new version of the Atlas family of launch vehicles, the Atlas IIAS to be used for the EOS AM-1 payload has not been well characterized with regard to the forcing functions imposed by the use of the solid strap-on boosters. It is important, therefore, that margin be built into the spacecraft to be able to withstand greater than expected loads. Conservative uncertainty factors should be employed in the dynamic analyses conducted on the spacecraft to help ensure that the spacecraft will be able to accommodate any increases that may occur in expected loads.

High modulus graphite epoxy structural elements are susceptible to impact damage that may not be visibly detectable. In such cases, the structural strength may be reduced up to 50 percent with no visible indications. To help avoid such undetected damage, the MMAS plans for protecting composite materials should be carefully examined and assessed for adequate attention to this matter. In addition, the feasibility of performing pre- and post-test inspections should be determined in order to verify the integrity of structural elements prior to preparation for launch. Such inspections, especially those conducted after shock tests, might include sonic testing to detect any debonding that may have occurred.

IDA

STRUCTURES AND MECHANISMS

- **Assessment (Continued):**
  - NEAs are New and Critical to Deployment Mechanisms
    - Encourage Close Monitoring of Planned Tests and Procedures
  - SAD Bearings and Slip Rings Contain Potential Single Points of Failure
    - Close Supervision of Tests and Manufacturing Procedures Required
  - Forcing Function of Atlas 2AS Solids is Not Well Characterized
    - Employ Conservative Uncertainty Factors in Dynamic Analyses to Ensure S/C Will be Able to Accommodate Significant Increases Over Predicted Loads
  - Non-Visible Impacts to Gr/Ep May Reduce Strength by 50%
    - Assess MMAS Composite Material Protection Plan
    - Determine Feasibility of Pre- and Post-Test Inspections of Structural Subsystem Integrity Prior to Launch
      - » Sonic Test Looking for Debonds—Especially After Shock Tests

THERMAL CONTROL

The EOS AM-1 thermal control subsystem contains a number of components, including heat rejection radiators, the capillary-pumped heat transport system (CPHTS), electronics subsystems for control of spacecraft temperatures, and thermal control sensors. Some of these thermal control elements involve new hardware and/or new capabilities. Two items that fall in this category are the CPHTS and heater control for the spacecraft battery subsystem.

The CPHTS, a new capability for heat transport, has undergone ground testing at GSFC and SWALES. A prototype system underwent flight testing in the Capillary Assist Pumped Loop (CAPL) - 1 experiment on the Space Shuttle during the STS-60 mission in February 1994. During this experiment, the pump exhibited anomalous start-up performance. The pump has since been redesigned, and testing is to continue with the CAPL-2 experiment scheduled to fly on STS 69 in July 1995.

The requirement for the thermal control of the spacecraft batteries calls for a thermal gradient of less than 3 °C across the 54 batteries. To accomplish this, a subsystem consisting of 18 heaters and 108 thermistors are controlled by the spacecraft controls computer (SCC).

Our assessment of the thermal control subsystem is that the thermal models being used are quite mature and indicate that substantial thermal control margins are being built into the system. The conventional, passive control mechanisms used as part of the thermal control system are based on well-proven techniques and are considered low risk.

IDA

THERMAL CONTROL

- **Components:**
  - Radiators, CPHTS, Heaters and Control Electronics, Sensors
- **New Hardware and New Capabilities:**
  - Capillary-Pumped Heat Transport System (CPHTS)
    - Testing at GSFC and OAO, STS CAPL 1 (with Anomalous Starts)
    - CAPL 2 Flight Scheduled for July 1995
  - 18 Heaters and 108 Thermistors Controlled by SCC to Maintain < 3 °C Gradient Across Batteries
- **Assessment:**
  - Thermal Models Mature and Indicate Substantial Margins
  - Conventional (Passive) Control Well-Proven and Considered Low Risk

THERMAL CONTROL (CONTINUED)

The stringent battery thermal gradient requirement of 3 °C across the batteries should be re-verified since it drives the system design. Conventional practice indicates that a 5 °C gradient is more typical for NiH_2 batteries.

The CPHTS has never been fully flight proven and a successful CAPL-2 flight test on the Space Shuttle will help in this regard by reducing some of the uncertainty. It appears that no alternatives on parallel development paths are being pursued. This could lead to a schedule risk if the CAPL-2 test fails or is otherwise unsuccessful. In this connection, lifetime issues regarding the operation of CPHTS in zero-g are not clear, especially with regard to the degradation of the wick material or of the tubing. With regard to the latter, the contamination control procedures for possible NH_3 leakage need to be thoroughly worked through. Another area of concern involves the effects of possible contamination, such as particulates, on CPHTS operation. To help in these areas, it is suggested that the Final Analysis Inc. satellite (FAISAT) CPL (capillary) experiment be assessed for relevance to the EOS AM-1 spacecraft. The FAISAT experiment is currently on orbit, but its CPL experiment has not yet been conducted.

IDA

THERMAL CONTROL

- **Assessment (Continued):**
  - Verify Battery Thermal Gradient Requirement (3 °C)
    - 5 °C Gradient More Typical for NiH_2 Batteries
  - CPHTS:
    - Design Has Never Been Fully Flight Proven
      - A Successful CAPL 2 Will Eliminate Some of the Uncertainty
    - Alternatives are Not Being Pursued on a Parallel Development Path; May Result in Schedule Risk
    - Lifetime Issues in O-g Unclear (e.g., Degradation of Wick or Tubing?)
    - Contamination Control Procedures (NH_3) and Possible Effects of Particulates on Operation Unclear
    - Examine FAISAT CPL Experiment to Assess Relevance to EOS
      - Currently On Orbit—Experiment Has Not Yet Begun

ELECTRICAL POWER SUBSYSTEM

The Electrical Power Subsystem consists of a number of sub-elements, namely, the solar array drive (SAD), the array drive electronics (ADE), the solar array assembly (SAA), the solar sequential shunt unit (SSU), the power distribution unit (PDU), the NiH_2 batteries, the battery power conditioner (BPC), the pyro relay assembly, the harness assembly, and the signal reference plane (SRP).

New hardware and/or new capabilities that have been included in the electrical power subsystem are the solar array and the 120-volt bus. The GaAs/Ge solar array being built by TRW is approximately 1.5 times larger in size than any existing, qualified design. The deployment mechanism for the solar array uses a total of seven of the non-explosive actuators (NEAs) recently incorporated into the design. As noted earlier, the NEAs have no space heritage. The drive bearings and slip rings associated with the solar array drive constitute a potential single point of failure as there is no redundancy here. The board to be used in qualification tests (Q-Board) has experienced excessive cell cracking thought to result from excessive force during back side soldering of the GaAs cells. A TRW Tiger Team was formed to explore the causes behind the cracking phenomena. It is now believed that the cause has been found and changes in the manufacturing process were expected in late February 1995. Satisfactory resolution of the problem is now expected in July 1995.

IDA

ELECTRICAL POWER SUBSYSTEM

- **Components:**
  - Solar Array Drive, Array Drive Electronics, Solar Array Assembly, Solar Shunt Unit, Power Distribution Unit, Batteries and Power Conditioner, Pyro Relay Assembly, Harness, Signal Reference Plane
- **New Hardware and New Capabilities:**
  - TRW'S GaAs/Ge Solar Array
    - ~1.5 Times Larger Than Existing Qualified Design
    - Deployment Mechanism Uses 7 Non-Explosive Actuators (NEAs)
    - Solar Array Drive Bearings and Slip Rings Potential Single Points of Failure
    - Q-Board has Experienced Excessive Cell Cracking
      - » Tiger Team Formed and Cause Believed to be Known
      - » Process Changes Expected by Late February 1995

ELECTRICAL POWER SUBSYSTEM (CONTINUED)

The electrical subsystem incorporates a new 120-volt design. Voltage systems higher than the conventional 28-volt spacecraft systems exist at 50, 70, and 100 volts. It has been shown that for spacecraft which require power in excess of 2 kilowatts (the maximum EOS AM-1 power design load is 2.5 kW), a higher-voltage system results in lower weight and volume, relative to the conventional 28-volt system. This is because a higher-voltage system runs with lower current and thus the spacecraft can be designed with smaller, lighter wiring. One disadvantage of using a 120-volt power system is the slightly lower reliability that would be achieved due to the necessary addition of voltage converters to bring some of the power to 28 volts for use in certain pieces of equipment. A second disadvantage is the increased risks of shock encountered by the integration personnel. The decision to use a 120-volt system also led to the requirement for numerous piece parts to be qualified for 120-volt operation, a process which led to extra costs. This qualification, however, has already been completed.

The assessment for the electrical power subsystem concludes that the design appears adequate and capable of meeting the EOS AM-1 mission requirements and the comprehensive engineering tests necessary to mitigate risk are underway. Concerns remain, however, with regard to the solar array, where it is felt that differential thermal contraction occurring during eclipses might cause mechanical damage or distortion. The non-linear analysis necessary to address this problem analytically is difficult, and current program plans call for only subscale testing (one panel) of the array. An expanded subscale test is recommended, and care should be undertaken to clearly understand how an extrapolation of results to a full-scale array is accomplished. It is also noted that the solar array deployment mechanism is very sensitive to design and workmanship and that extreme care must be taken to ensure that these aspects receive the necessary attention.

ELECTRICAL POWER SUBSYSTEM

- **New Hardware and New Capabilities (Continued):**
  - 120 V Bus:
    - New Design Although Bus Voltages of 50, 70, and 100 V Exist
    - Provides Lower Weight and Volume (for Power > 2 kW)
    - Slightly Lower Reliability Due to Added Components (e.g., converters for 120 V to 28 V)
    - Qualification of Piece Parts (All Parts Now Qualified)
- **Assessment:**
  - Design Appears Capable of Meeting Mission Requirements
  - Comprehensive Engineering Tests Underway to Mitigate Risk
  - Solar Array Concerns:
    - Differential Thermal Contraction During Eclipse May Cause Mechanical Damage or Distortion (Nonlinear Analysis Difficult)
    - Current Plans Call for Subscale Testing (1 Panel Only—Extrapolation of Result Needs to be Clearly Understood)
    - Deployment Mechanism is Sensitive to Design and Workmanship

GUIDANCE, NAVIGATION AND CONTROL

The guidance, navigation and control (GN&C) subsystem comprises the following components: reaction wheel assembly (RWA), attitude control electronics (ACE), inertial reference unit (IRU), star trackers (STs), earth sensor asssembly (ESA), three-axis magnetometer (TAM), magnetic torque rods (MTRs), and sun sensor assembly (SSA).

New hardware and/or capabilities that have been incorporated into the GN&C subsystem include a new lens assembly for the solid state star tracker (SSST) to address a stability problem that occurred in the previous design, a 120-volt modification to the reaction wheel assembly, and a new lubricant for the earth sensor assembly. The new lubricant was introduced because of difficulties experienced with other lubricants in prior on-orbit situations. The new lubricant is a Pennzane grease and oil that contains antiwear and antioxidant additives.

The assessment of the GN&C subsystem is that it appears adequate and capable of meeting the needs of the AM-1 spacecraft. The fault detection, isolation, and recovery (FDIR) system will protect the system from loss of attitude control.

IDA

GUIDANCE, NAVIGATION AND CONTROL

- **Components:**
  - Reaction Wheel Assembly, Attitude Control Electronics, Inertial Reference Unit, Star Trackers, Earth Sensor, Three-Axis Magnetometer, Magnetic Torque Rods, Sun Sensors
- **New Hardware and New Capabilities:**
  - Lens Assembly for Solid State Star Tracker (SSST)
  - 120 V Modification to Reaction Wheel Assembly (RWA)
  - New Lubricant (Pennzane) for Earth Sensor Assembly (ESA)
- **Assessment:**
  - Fault Detection, Isolation, and Recovery (FDIR) Protects Against Loss of Attitude Control
  - The GN&C Subsystem Appears Robust

PROPULSION

The propulsion subsystem contains the following components: the propellant tank (PT); the propulsion module electronics assembly (PMEA); isolation latch valves; and 5-lbf and 1-lbf thrusters and associated tubing, transducers, and support structure. The propulsion subsystem incorporates a slightly new design based on a very simple architecture. It uses an N_2H_4 monopropellant, pressurized "blowdown" system that has the propellant lines "wet" completely to the thrusters. The design is based on experience gained from a number of recent failures of propulsion systems on previous MMAS-designed spacecraft.

Our assessment of the propulsion subsystem is that it is a simple design which should not invite problems. Some concern is registered, however, given the history of MMAS propulsion system troubles. Some of these problems may have resulted from process control inadequacies, especially with regard to contamination. It is recommended that close oversight be imposed by GSFC; this oversight may warrant a review of the overall propulsion system and the process control and manufacturing procedures.

PROPULSION

- **Components:**
  - Tank, Propulsion Module Electronics Assembly, Latching Isolation Valves, Thrusters
- **New Hardware and New Capabilities:**
  - Slightly New Design—Very Simple Architecture
    - N_2H_4 Monoprop "Blowdown" System, Lines "Wet" Down to Thrusters
- **Assessment:**
  - Simple Propulsion Design
  - Concern From MMAS History of Propulsion Systems and Process (e.g., Contamination)
    - Close Oversight from GSFC Required
      - » A Review of System, Process Control and Manufacturing Procedures May Be Warranted

COMMAND AND DATA HANDLING AND SOFTWARE

The Command and Data Handling (C&DH) and Software subsystems contain the following major components: the Spacecraft Controls Computer (SCC), the Command and Telemetry Interface Unit (CTIU), the Science Formatting Equipment (SFE) and the Solid-State Recorder (SSR).

New hardware and/or capabilities that have been incorporated into the EOS AM-1 spacecraft in this sub-area are the high-data-rate throughput of the SFE, the increased storage capability of the SSR, the CTIU PROM-based software development, and the choice of RTX, a new operating system. Some of the important engineering tests associated with these developments were not completed prior to CDR, but are scheduled later in 1995.

The assessment conducted by the Review Panel concluded that the C&DH and Software progress appears relatively mature for this point in the design program and developments appear to be "on track." It was noted that since the run-time system (RTX) is a new capability (essentially a beta version), it may be desirable to consider more standard alternative options (such as SPK) if the RTX operating system turns out to be too "buggy."

C&DH AND SOFTWARE

- **Components:**
  - Spacecraft Controls Computer (SCC), Command and Telemetry Interface Unit (CTIU), Science Formatting Equipment (SFE), Solid-State Recorder (SSR)
- **New Hardware and New Capabilities:**
  - High Data Rate Throughput of SFE (ETM 4/95)
  - Solid State Recorder
  - CTIU PROM-Based S/W Development (TRR 9/95)
- **Assessment:**
  - C&DH and S/W Progress Appears to be Relatively Mature and "On-Track"
  - Run-Time System (RTX) is New
    - Consider Options (e.g., SPK) if RTX is Too "Buggy"

COMMAND AND DATA HANDLING AND SOFTWARE (CONTINUED)

The Panel found that uplinking the SCC software from the ground may require several ground contacts for successful completion. To avoid this operational procedure and any problems that might be associated with it, consideration should be given to placing a copy of the SCC software in the PROM. It was observed that currently less than 50 percent of the PROM is utilized for other purposes, suggesting adequate space is available.

It was also observed by the Panel that if the CTIU encounters difficulties or otherwise "hangs up," the back-up CTIU must provide a software re-boot. Consideration should therefore be given to adding a ground uplink capability to provide a hardware decoded reset command to the CTIU, thus adding an additional level of redundancy.

C&DH AND SOFTWARE

- **Assessment (Continued):**
  - Uplink of SCC S/W Will Require Several Ground Contacts
    - Consider Putting Copy of SCC S/W in PROM
      - » Currently < 50% PROM Utilized
  - Currently If the CTIU "Hangs-Up," the Back-Up CTIU Must Provide a S/W Re-boot
    - Consider Adding Ground Uplinked H/W Decoded Reset Command to CTIU

COMMUNICATIONS

A number of components comprise the spacecraft communications subsystem. These components fall in the categories of Command/Telemetry (CMD/TLM), Science Data, and Ku-Band Single Access (KSA) Communications. The CMD/TLM category includes the High Gain Antenna (HGA) used for both Ku-Band and S-Band communications plus the associated S-Band master oscillator; the two S-Band transponders that are designated prime and redundant; the S-Band Interface Unit (SBIU), the two Omni S-Band antennas designated Nadir and Zenith; and the Direct Access System (DAS), which operates at X-Band and includes the DAS Antenna, Modulator, Upconverter, and RF amplifier.

Several aspects of the Communications Subsystem contain the following new hardware/ capabilities:

- The new Pennzane lubricant is used in the High Gain Antenna as it is in the Earth Sensor Assembly.
- The Master Oscillator is a new design incorporated to alleviate concerns with temperature and radiation sensitivity.
- The KSA and DAS Modulators also incorporate new designs.

Our assessment of the Communications Subsystem is that standard design practices are utilized which incorporate mature hardware components. There appears to be sufficient redundancy and other design features to assure low risk. The HGA deployment mechanism employs some five NEAs and requires careful design and quality workmanship.

We also found that for the event in which EOS AM-1 is forced to rely on the direct playback mode for data collection, contingency plans are not fully defined. We note that the responsibility for these plans does not lie with the EOS Spacecraft Project but needs to be defined if the contingency plans are to be meaningful.

IDA

COMMUNICATIONS

- **Components:**
  - HGA (Ku and S-Band), Two Omni S-Band, DAS (X-Band)
- **New Hardware and New Capabilities**
  - Lubricant (Pennzane) in High Gain Antenna
  - Master Oscillator
  - KSA and DAS Modulators
- **Assessment:**
  - Sufficient Redundancy and Low Risk
  - Contingency Plans for Use of Direct Playback On Orbit Not Fully Defined
  - HGA Deployment Employs 5 NEAs and is Sensitive to Design and Workmanship
  - Standard Design With Mature H/W Components

INTEGRATION AND TEST (I&T) AND OPERATIONS

A Panel concern with the I&T Operations derives from the fact that the *final* calibration of all of the scientific instruments carried on the spacecraft is performed at their respective home institutions prior to integration and test at MMAS. These instruments all have stressing absolute radiometric accuracy and modulation transfer function (MTF) requirements. The instruments are scheduled for some 1,000 hours of operation during integration and test after reaching MMAS, following their final calibration. The I&T operations include greater than four temperature cycles during thermal/vacuum tests, and acoustic tests and shock tests.

This situation leads to the following Panel assessments: With no *external* characterization sources available or planned at MMAS, then only *internal* characterization, which implies near field operation, is performed after the instruments have left their home institutions. Thus, no check on the MTF is allowed. There is also no radiometric check in the infrared (IR) after the thermal vacuum (T/V) testing which is scheduled to occur in July–August 1997. This means there is no long-term stability check of the IR focal plane array (FPA) or internal calibration sources. Calibration sources are often unstable and therefore a check of them is highly desirable. Focal plane sensitivity is known to change over time and, under the current plan, the sensitivity will last be checked 1 year prior to launch. It is also of concern that system level EMI/RFI tests on IR instruments do not appear possible. However, in this case the 6-dB margin built into the design of the instruments is estimated to provide the added assurance needed.

I&T AND OPERATIONS

- *Final* Calibration Performed at Home Institution
  - Instruments Have Stressing Absolute Radiometric Accuracy and MTF Requirements
  - After Calibration: Instruments Shipped to MMAS, > 4 Temperature Cycles, Acoustic Tested, Shock Tested
    - ~1000 Hours of Operation Anticipated
- Assessment:
  - No *External* Characterization Sources Planned at MMAS
    - Internal (Near Field) Only—No Check on MTF
  - No Radiometric Check in IR after T/V (July-Aug. 1997)
    - No Long-Term Stability Check of IR FPA or Cal Sources
  - System Level EMI/RFI Tests on IR Instruments Probably Not Attainable (But 6 dB Margin Exists in Design)

INTEGRATION AND TEST (I&T) AND OPERATIONS (CONTINUED)

Also of concern to the Panel is the fact that the *Standard* Atlas IIAS acoustic spectrum supplied by the Air Force is not a conservative spectrum with regard to designing hardware that must interact with it. It is a spectrum that has been *observed* to date by the Air Force in operation of the launch vehicle. As such, it is a spectrum that is based on limited flight operations and does not account for possible variations that may occur from flight to flight. To ensure adequate performance for system-level acoustic testing, it is recommended that GSFC review the acoustic spectrum associated with the Atlas IIAS launch vehicle for sufficient conservatism. The GSFC review should include appropriate consideration of the fairing length and fill factors associated with the launch vehicle and assure that the spectrum is thus properly adjusted.

Additional concerns noted by the Panel were that the Mission Operations Review is scheduled to occur relatively late in the development program. It is currently scheduled for June 1996, which is well into the I&T portion of the program. Also the T/V testing occurs before the acoustic and vibration testing rather than the other way around. We would prefer any issues regarding mission operations to be settled prior to systems testing.

IDA

I&T AND OPERATIONS

- **Assessment (Continued):**
  - *Standard* Atlas 2AS Acoustic Spectrum Not Conservative (Based on USAF Experience)
    - Spectrum Based on Nominal Flight Conditions
    - Flight-to-Flight Variations Not Accounted For
    - GSFC Should Review Acoustic Spectrum to Ensure Sufficient Conservatism is Included for System Level Acoustic Test
      - » Ensure Spectrum Properly Adjusted for Fairing Length and Fill Factor Modifications
  - Mission Operations Review Occurs Relatively Late in the Program (6/96)
    - Well Into I&T Portion of Program

OUTLINE (AGENDA FOCUS)

The discussion will now focus on a higher-level category of concerns, the so-called Program-Level Concerns. These concerns deal with top-level topics, including:

1. Increased schedule risk posed by the incorporation of new and/or modified hardware into the system design.
2. The numerous technical hurdles that still need to be cleared as a result of not having been resolved prior to CDR.
3. The concern that the design of the system, including the system specifications and the associated risks, has been driven mainly by the two instruments, ASTER and MOPITT. The accommodations required by these instruments increase schedule risk associated with the system.
4. Additional schedule risk posed by the use of new facilities, which may not be ready when needed, to carry out the program.

IDA

OUTLINE

- Overview
- Spacecraft Systems Assessment
- Program-Level Concerns
  - New and Modified Hardware Increases Schedule Risk
  - Numerous Technical Hurdles Still to be Cleared
  - Design of Spacecraft Driven by ASTER and MOPITT
  - New Facilities Provide Schedule Risk
- Summary and Recommendations

IV. PROGRAM-LEVEL CONCERNS

NEW AND MODIFIED HARDWARE (H/W) INCREASES RISK

For the purposes of this discussion, two categories of hardware used in the EOS AM-1 spacecraft have been specified: components that have not had previous flight experience, i.e., no flight heritage, and components that have had some previous flight experience but where the design now involves some modification of, or extension from, their flight-proven capabilities.

The major components in the system that have no flight heritage include the non-explosive actuators (NEAs); the capillary pumped heat transport system (CPHTS), the concept for which is expected to be the subject of an additional Space Shuttle flight experiment in July 1995; and the solar array assembly (SAA), which is to begin a lifetime test in the fourth quarter of 1995.

Also, a large number of the major components in the system have extensions or modifications from flight capabilities that have been previously proven in flight operations. Several of the more important include the solid state recorder (SSR), which will undergo protoflight hardware test in October 1995; the solar array drive (SAD) and electronics, which will undergo lifetime testing in the second quarter of 1996; and the NiH_2 battery assemblies, which will undergo lifetime testing through 1999. Note that although the level of concern about the lack of more relevant experience in flight-proven operations varies, all the components have been shown on the chart for completeness.

Considering that the primary purpose for the EOS program is to collect scientific data and not necessarily to develop new satellite technology, it appears that an excessively large number of components either have no flight heritage or require considerable extension or modifications to proven capabilities. Although there may not be great concern over the risk associated with any one particular item that has been included on the list, there is concern that the fairly large number of new or modified hardware items does provide a significant increase to the schedule risk associated with the program. As noted, there are a number of components that require engineering model testing and some that will be undergoing life testing for some time to come.

IDA

NEW AND MODIFIED H/W INCREASES RISK

- **Components Without Flight Heritage:**
  - Non-Explosive Actuators (NEAs)
  - Capillary Pumped Heat Transport System (CPHTS) - CAPL2 7/95
  - Solar Array Assembly (SAA) - Life Test 4Q95
- **Components With Extension of Flight-Proven Capabilities:**
  - Solid State Recorder (SSR) - Protoflight 10/95
  - Solar Array Drive (SAD) and Electronics - Life Test 2Q96
  - NiH_2 Battery Assemblies - Life Test 1999
  - Electronics and Battery Power Conditioner (EPC and BPC) - ETM 1Q95
  - Solid State Star Tracker (SSST) Lens Assembly - Deliv 5/95
  - ESA and HGA Lubricant (Pennzane) - Life Test 3/97
  - Propulsion Module Electronics Assembly
  - Science Formatting Equipment (SFE) - ETM 4/95
  - Ku-Band Single Access (KSA) and DAS Modulators - ETM 3Q95
  - Direct Access System Solid State Power Amplifier ...

⇨ **Large Number of New and Modified Items Provide Concern**

TECHNICAL PERFORMANCE STILL TO BE PROVEN

At the Critical Design Review, MMAS identified a number of areas associated with the EOS AM-1 spacecraft development that are considered "Moderate Risk." Each of these items has technical aspects that need further resolution before the risk designation can be reduced. The following areas fall into this category: the deployment mechanism and the GaAs solar cell flexible blanket of the solar array assembly (SAA); the lifetime of the bearings and slip rings associated with the solar array drive (SAD); the complexities and the lifetime associated with the battery assembly; the capillary-pumped heat transport system (CPHTS) with regard to obtaining results from the planned zero-g Space Shuttle reflight experiment; the command and telemetry interface unit (CTIU); the high-data-rate throughput associated with the science formatting equipment (SFE); the launch loads, acoustic loads and the shock loads associated with the launch on the relatively new Atlas IIAS launch vehicle, plus any problems associated with bringing the Atlas IIAS launch pad and payload processing building to readiness; any electromagnetic compatibility problems; and any interference and disturbance problems associated with possible interactions between the instruments, their associated support equipment, and the spacecraft itself. Also of concern is the lifetime associated with the cryogenic coolers used in conjunction with two of the scientific instruments, even though this topic was not appropriate for inclusion and discussion in the EOS AM-1 spacecraft CDR.

Thus, it is noted that there is a rather extensive list of items categorized as adding moderate risk to the program. Undoubtedly these risk items will be resolved prior to flight; however, in order to ensure an on-schedule launch it would seem prudent that more contingency planning be conducted, especially for those items that are more critical for program success. For example, items involving critical failure possibilities such as the solar cells or solar array deployment and drive mechanisms perhaps should have back-up designs proceeding in parallel that could serve as possible fall-back positions in case of lack of satisfactory resolution of problem areas. Taking such precautions would increase the likelihood of program success by lowering the risk currently associated with the program.

TECHNICAL PERFORMANCE STILL TO BE PROVEN

- "Moderate" Risk Items (from CDR):
  - Solar Array Assembly (Deployment Mechanism, Flexible Blanket GaAs Solar Cells)
  - Solar Array Drive (Bearing and Slip Rings Lifetime)
  - Battery Assembly (Complexities and Lifetime)
  - Capillary-Pumped Heat Transport System (Zero-G Reflight Experiment)
  - Command Telemetry Interface Unit (CTIU)
  - Science Formatting Equipment (High Data Rate Throughput)
  - Launch Vehicle Issues (Loads, Acoustics, Shock, Schedule)
  - Electromagnetic Compatibility/Interference and Disturbances (Instrument/Spacecraft Interactions)
  - S/C Pointing (Instrument Disturbances)
  - Instrument Cryogenic Cooler Lifetime (Not in S/C CDR)

A Number of Moderate Risk Items Have No Back-Up Designs in Parallel

SPACECRAFT DRIVEN BY ASTER AND MOPITT

The Panel registered concern that most of the moderate risk items associated with the EOS AM-1 spacecraft result from accommodating two of the scientific instruments, ASTER and MOPITT. Were it not for these two instruments on AM-1, the spacecraft design could be simplified and the associated risk greatly reduced.

As examples of the driving influence of these instruments, it was reported in the Project Brief on January 18, 1995, that "ASTER drives pointing performance," and in the CDR that "ASTER is the most driving instrument on the spacecraft." As currently planned, ASTER accounts for 39 percent of the instruments' weight, accounts for 44 percent of the average power consumption and 47 percent of the peak power, and accounts for 82 percent of the peak data rate and 51 percent of the end of life (EOL) Solid State Recorder (SSR) data storage. Similarly, MOPITT accounts for 21 percent of the instruments' weight and 15 percent of the average power consumption.

There is also Panel concern with regard to the potential impact of ASTER and MOPITT on other sensors. The possibility of jitter is a concern from the Stirling-cycle cryogenic coolers associated with the thermal infrared (TIR) and short wave infrared (SWIR) sensors. Also, the TIR pointing mirror generates large forces in the Y/Z plane of the spacecraft and this disturbance could occur up to 20 times per orbit of spacecraft operation. A direct down link capability has been incorporated in the spacecraft in response only to ASTER requirements. Furthermore, ASTER and MOPITT are the only sensors that utilize the CPHTS. These instruments also drive the requirements for a number of the new hardware components used in the spacecraft system. Most of the moderate risk items from the previous chart would not be necessary without the requirement to support ASTER and/or MOPITT.

It is the conclusion of the Panel that the risk associated with the spacecraft bus development is increased by the inclusion and accommodation of the ASTER and MOPITT instruments. These appear not to be regarded as scientifically the most important instruments on the spacecraft, given that NASA's plans would allow AM-1 to be launched even if these instruments are not able to operate fully.

S/C DRIVEN BY ASTER AND MOPITT

- **These Instruments Driving S/C Requirements:**
  - "ASTER Drives Pointing Performance"—Project Brief (1/18/95)
  - "ASTER is the Most Driving Instrument on the S/C"—CDR
  - ASTER (MOPITT) Accounts for 39% (16%) Instrument Weight, 44% (21%) Avg. Power, 47% (15%) Peak Power, 45% Avg. Data Rate, 82% Peak Data Rate, 51% EOL SSR Storage
- **Potential Impact on Other Sensors:**
  - Jitter from TIR and SWIR Stirling Cycle Coolers
  - TIR Pointing Mirror has Large Forces in Y/Z Plane (~20x/orbit)
  - Direct Downlink for ASTER Only
  - Only Sensors Which Utilize CPHTS
  - A Number of New H/W Components Driven by ASTER and MOPITT

⇒ **S/C Risk Increased by Accommodating ASTER and MOPITT Sensors**

NEW FACILITIES PROVIDE RISK

Panel concern is associated with the requirement for new or extensively modified facilities for building and launching the EOS AM-1 spacecraft. MMAS is constructing a new integration and test (I&T) facility, Building 100, at its Valley Forge location. This facility is not scheduled for occupancy until December 1995, which is only one month before spacecraft I&T is scheduled to start. Similarly, a new launch pad, SLC-3E, is being constructed by the U.S. Air Force at Vandenberg Air Force Base (VAFB) for the Atlas IIAS launch vehicle. A new payload processing facility to be used by the EOS AM-1 spacecraft will be in Building 2520, also at VAFB. New capabilities being incorporated into the Atlas IIAS launch vehicle include a sizable fairing extension, a new spacecraft-launch vehicle adapter, and a Centaur upper stage equipment module.

A further concern noted by the Panel is that there is currently no "Pathfinder " launch of an Atlas IIAS launch vehicle from the new SLC-3E launch pad planned prior to the scheduled EOS AM-1 spacecraft launch.

IDA

NEW FACILITIES PROVIDE RISK

- New or Extensively Modified Facilities for EOS AM-1:
  - New MMAS I&T Facility (Bldg. 100—Occupancy 12/95)
  - AF Modifications to VAFB Launch Pad SLC-3E
  - VAFB Payload Processing Facility (Bldg. 2520)
  - Atlas IIAS Fairing Extension, S/C-ELV Adapter, Centaur Equipment Module

No Pathfinder Currently Planned for Atlas IIAS Launch from VAFB

OUTLINE (AGENDA FOCUS)

The focus of attention will now be on Summary and Recommendations sections.

IDA

OUTLINE

- Overview
- Spacecraft Systems Assessments
- Program-Level Concerns
- Summary and Recommendations

V. SUMMARY AND RECOMMENDATIONS

SUMMARY

Based upon the information presented at the CDR, we have come to the following conclusions with regard to the current status of the EOS AM-1 spacecraft program:

- It appears that the efforts of both Martin Marietta Astro Space (MMAS) and the Goddard Space Flight Center (GSFC) are technically "On Track." The satellite design appears viable and is far enough along to give us confidence that both MMAS and GSFC have a good understanding of the technical issues associated with the program.
- Where technical risks were identified, the spacecraft qualification and test programs appear adequate to reduce or mitigate the risks. The timeliness, however, with which these risks will be resolved appears as an issue.
- The *greatest* risk associated with the program at the present time appears to be maintaining schedule. As noted earlier, there are a number of technical issues yet to be resolved, and most of them do not have parallel back-up efforts underway. Failure to maintain schedule also is likely to result in an impact on the overall cost of the program. The main areas of concern in this regard are the following:

    1. The major impacts to the program if the solar array cracking resolution, the CPHTS flight test, and the many ongoing lifetime tests of various components are not concluded as successfully as anticipated
    2. The increased schedule risk resulting from the use of the large number of non-heritage components
    3. The major impact on the program that would result if the Atlas IIAS launch pad is delayed or otherwise unavailable when anticipated.

IDA

SUMMARY

- CDR Indicated Both MMAS and NASA Appear to be Technically “On Track”
- Where Technical Risk Exists, the Qualification and Test Program Appears Sufficient to Mitigate the Risk, But Timeliness is an Issue
- *The Greatest Risk We See is to Schedule* (Which Will Likely Impact Cost)
  - Major Impact to Program if Solar Array Cracking, CPHTS, and Other Tests are Not Resolved as Anticipated
  - Number of Non-Heritage Components Increase Schedule Risk
  - Lack of (or Delay of) ATLAS 2AS Pad Would Have Major Impact on Program

RECOMMENDATIONS

We make the following recommendations with regard to the current EOS AM-1 spacecraft program. The rationale for these recommendations can be found throughout the report.

In the area of **Hardware and Software**:

- Close oversight of the program should be provided in the area of the *Propulsion System and Procedures*.
- A *Hardware Decode Reset* should be provided to the CTIU.
- The *Software* for the Spacecraft Controls Computer should be loaded in the *PROM*.
- The use of the *RTX Run Time System* should be re-evaluated.
- The *Thermal Gradient Requirements* for the battery systems should be re-evaluated.
- The *CPL Experiment* on the Final Analysis Inc. satellite (FAISAT) should be examined for applicability to CPHTS.

In the area of **Operations**:

- Reschedule the *Mission Operations Review* to be more in line with I&T and End-to-End Testing.
- Define contingency plans for use of *Direct Playback* on orbit.

IDA

RECOMMENDATIONS

- **Hardware and Software:**
  - Provide Close Oversight of Propulsion System and Procedures
  - Add H/W Decode Reset to CTIU
  - Load SCC S/W in PROM
  - Reevaluate Use of RTX Run-Time System
  - Reevaluate Battery Thermal Gradient Requirements
  - Examine FAISAT CPL Experiment for Applicability to CPHTS
- **Operations:**
  - Reschedule Mission Operations Review to be More In Line With I&T and End-to-End Testing
  - Define Contingency Plans for Use of Direct Playback On Orbit

RECOMMENDATIONS (CONTINUED)

In the area of **Testing:**

- The *Sub-Scale Testing for the Solar Array* should be reviewed thoroughly to ensure acceptable extrapolation to EOS AM-1 can be accomplished.
- The *Atlas IIAS Acoustic Spectrum* should be carefully reviewed to ensure the spacecraft design incorporates adequate margin to handle a severe acoustic load.
- Add *external sources for scientific instrument characterization* during thermal/vacuum testing to verify optical alignment and focus (i.e., MTF) measurements of imagers.
- To prevent a 1-year gap in IR sensor check-out prior to launch, consideration should be given to conducting *thermal/vacuum testing after the acoustic and vibration testing*. The risk involved in this action would be the necessity of repeating the other tests if the thermal/vacuum testing fails.
- The feasibility should be assessed of conducting *sonic examinations of structural elements* after they have undergone shock testing to validate the structural integrity of the graphite epoxy bonds.

RECOMMENDATIONS (Continued)

- **Testing:**
  - Review Solar Array Sub-Scale Testing to Ensure Accurate Extrapolation to EOS AM-1
  - Review Atlas Acoustic Spectrum to Ensure Tests Provide Adequate Margin
  - Add External Characterization Sources During T/V to Verify Optical Alignment and Focus (i.e., MTF) of Imagers
  - Consider Switching T/V to After Acoustic and Vib Test (To Prevent 1 Year Gap Prior to Launch of IR Sensor Check-Out)—Risk is of Repeating Other Tests if T/V Failure
  - Assess Feasibility of Sonic Examination of Structure After Shock Test to Validate Structural Integrity of Gr/Ep Bonds

RECOMMENDATIONS (CONTINUED)

Contingency Plans for Alternative Approaches (with associated funding) should be developed for each of the more likely *Critical* failure scenarios.

Consideration should be given to forming Tiger Teams to examine the impact if any of the following were to happen:

- The new *MMAS I&T facility* is not ready on time.
- The VAFB *Atlas IIAS launch facility* is not available when needed.
- Spacecraft *"Moderate Risk"* items are not resolved in a timely manner.
- Results of *Lifetime Tests* of critical spacecraft components are not satisfactory.

Priorities should be established for Program Objectives and focus placed on "Radical" contingency solutions emphasizing the importance of the Primary Scientific Instruments.

OVERALL CONCLUSION AND RECOMMENDATION

EOS AM-1 is an ambitious program with a significant amount of innovative hardware and moderate schedule risk.

Contingencies should be developed to help ensure an on-schedule (and cost) delivery.

IDA

RECOMMENDATIONS (Continued)

- **Develop Contingencies (Funding and Alternatives) for Each of the More Likely *Critical* Failure Scenarios**
  - **Consider Forming a Tiger Team to Examine Impact if:**
    - » **MMAS New I&T Facility is Not Ready on Time**
    - » **VAFB Launch Facility is Not Available When Needed**
    - » **S/C "Moderate" Risk Items Not Resolved in a Timely Manner**
    - » **Life Test Results of Critical S/C Components are unsatisfactory**
  - **Set Priorities on Program Objectives and Consider "Radical" Solutions Focusing on Primary Instruments**

EOS AM-1 Is an Ambitious Program With a Significant Amount of Innovative Hardware. Contingencies Should be Developed to Help Ensure an On-Schedule (and Cost) Delivery.

GLOSSARY

ACE	Attitude Control Electronics
ADE	Array Drive Electronics
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BPC	Battery Power Conditioner
C&DH	Command and Data Handling System
CAPL	Capillary Assist Pumped Loop
CDR	Critical Design Review
CERES	Cloud and Earth's Radiant Energy System
CMD/TLM	Command/Telemetry
CPHTS	Capillary-Pumped Heat Transport System
CPL	Capillary
CTIU	Command and Telemetry Interface Unit
DAS	Direct Access System
EIRR	External Independent Readiness Review
EOL	End of Life
EOS	Earth Observation System
ESA	Earth Sensor Assembly
ETM	Engineering Test Model
FAISAT	Final Analysis Inc. Satellite
FDIR	Fault Detection, Isolation, and Recovery
FPA	Focal Plane Array

GN&C	Guidance, Navigation, and Control
GrEp	Graphite-Epoxy
GSFC	Goddard Space Flight Center
HGA	High-Gain Antenna
H/W	Hardware
I&T	Integration and Test
IR	Infrared
IRU	Inertial Reference Unit
KSA	Ku-Band Single Access
MISR	Multi-angle Imaging Spectro-Radiometer
MMAS	Martin Marietta Astro Space
MODIS	Moderate Resolution Imaging Spectro-Radiometer
MOPITT	Measurements of Pollution in the Troposphere
MPTE	Mission to Planet Earth
MTF	Modulation Transfer Function
MTR	Magnetic Torque Rod
NEA	Non-Explosive Actuator
PDR	Preliminary Design Review
PDU	Power Distribution Unit
PMEA	Propulsion Module Electronics Assembly
PROM	Programmable Read-Only Memory
PT	Propellant Tank
RWA	Reaction Wheel Assembly
SAA	Solar Array Assembly
SAD	Solar Array Deployment
SAD	Solar Array Drive
SBIU	S-Band Interface Unit
SCC	Spacecraft Controls Computer

SFE	Science Formatting Equipment
SRP	Signal Reference Plane
SSA	Sun Sensor Assembly
SSR	Solid-State Recorder
SSST	Solid State Star Tracker
SSU	Sequential Shunt Unit
ST	Star Tracker
SWIR	Short-Wave Infrared
T/V	Thermal Vacuum
TAM	Three-Axis Magnetometer
TDRSS	Tracking and Data Relay Satellite System
TIR	Thermal Infrared
TRR	Technical Requirements Review
VAFB	Vandenberg Air Force Base

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
July 1995

3. REPORT TYPE AND DATES COVERED
Final—January 1995–July 1995

4. TITLE AND SUBTITLE
External Independent Readiness Review: EOS AM-1 CDR

5. FUNDING NUMBERS
DASW01 94 C 0054
T-AG1-1369

6. AUTHOR(S)
David Braverman, Thomas Buckler, Charles Cook,
Nelson Hyman, William Jeffrey, Paul Regeon, Robert E. Roberts,
Ernest Scheyhing, Jeffrey Short, Maile Smith, Charles Wilderman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Institute for Defense Analyses
1801 N. Beauregard St.
Alexandria, VA 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Paper P-3083

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NASA HQ
Washington, DC

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 180 words)***

IDA was tasked to conduct an External Independent Readiness Review (EIRR) of the EOS AM-1 spacecraft following the Critical Design Review (CDR). The briefing provides an overview, which covers the EIRR participants, the EIRR process, and the Overall Assessment resulting from the EIRR; a Spacecraft Systems Assessment, which contains a subsystem-by-subsystem assessment of the EOS AM-1; a discussion of higher level (i.e., Program level) concerns; and a summary and recommendations. EOS AM-1 is an ambitious program with a significant amount of innovative hardware and moderate schedule risk. The greatest risk associated with the program at the present time appears to be maintaining schedule. Major areas of concern are the following: (1) impact on the program if solar array cracking resolution and the many ongoing lifetime tests of various components are not concluded as successfully as anticipated; (2) the increased schedule risk resulting from the use of a large number of components with no space heritage; and (3) impact on the program should the Atlas IIAS launch pad be delayed or otherwise unavailable when anticipated.

14. SUBJECT TERMS
EOS, AM-1, EIRR

15. NUMBER OF PAGES
71

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102